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VERIFICATION OF TRANSLATION

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I verify that the attached English translation is a true and correct translation made by me of the attached further Amended Pages in the German language of International Application PCT/EP00/08745;

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Method of reactive power regulation and apparatus for producing electrical energy in an electrical network

The invention concerns a method of reactive power regulation in an electrical network, in which electrical power is produced by an electrical generator preferably driven by the rotor of a wind power installation and suitably modulated by means of a compensation device between the generator and the network for the compensation of reactive power. The invention further concerns an apparatus for producing electrical energy in an electrical network, comprising an electrical generator preferably driven by the rotor of a wind power installation and a compensation device between the generator and the network for the compensation of reactive power.

Many consumers connected to the electrical network require inductive reactive power. Compensation of such an inductive reactive power component is effected by using capacitors which are also referred to as phase-shifting capacitors whose capacitive reactance is approximately as high as the inductive reactance. Complete compensation of the inductive reactive power by means of phase-shifting capacitors is however not possible in practice precisely when high power fluctuations are involved. A further disadvantage is that the phase-shifting capacitors required, which are frequently combined together to form what is referred to as capacitor batteries and which moreover take up a great deal of space have a negative effect on the stability of the electrical network.

The object of the present invention is to avoid the above-mentioned disadvantages of the state of the art and to compensate for the reactive power in an electrical network in a simple fashion.

In a method and an apparatus of the kind set forth in the opening part of this specification, that object is attained in that the compensation device is so regulated that the electrical power delivered to the consumer

has a reactive power component which is adapted in respect of its phase, amplitude and/or frequency to the consumer in such a way as to compensate for the reactive power in the consumer.

In accordance with the invention, by means of the compensation device, a reactive power is 'produced', which is in a position to compensate for the reactive power in the consumer. For example, by means of the compensation device according to the invention, it is possible to produce a capacitive reactive power component which is adapted to the inductive reactive power component required by the consumer, in such a way that it substantially completely compensates for the inductive reactive power component in the consumer. The advantage of the invention is thus essentially that there is provided a regulating system which rapidly reacts in particular to frequently occurring high power fluctuations, so that complete reactive power compensation is substantially maintained. Accordingly, inductive or capacitive reactive power can be fed selectively into the electrical network, which in accordance with the invention is implemented by regulation of the compensation device.

In this respect, by means of the regulation in accordance with the invention, it is preferably also possible for the electrical power produced to be of a frequency which corresponds to the frequency of the consumer or also represents a multiple of the consumer frequency. In the former case accordingly reactive power can be supplied at the frequency of the consumer or the network frequency of the electrical network. In the latter case for example as desired harmonic reactive power can be fed into the electrical network. For example the fifth harmonic can be fed into the network, at a frequency of 250 Hz, as a capacitive harmonic. That then compensates for the harmonic reactive power of electrical consumers which are connected to the electrical network such as for example televisions, energy-saving lamps and so forth.

Desirably the compensation device has an inverter with which phase, amplitude and/or frequency of the voltage and/or current characteristics can be particularly easily adjusted or regulated in order to produce a

reactive power component which is suitable for appropriately compensating for the reactive power in the consumer.

Preferably the compensation device has a measuring device for detecting the voltage and/or current variations in the electrical network, preferably at the feed-in point. In a development of the embodiment in which the compensation device includes an inverter the compensation device controls the inverter in dependence on the measurement results of the measuring device.

The voltage produced by the electrical generator is preferably regulated substantially to a predetermined reference value with suitable adaptation of the reactive power component in the electrical power delivered to the consumer. In that situation adaptation of the reactive power component can take place by suitable control of the power factor (cos φ) or the phase of the current produced by the electrical generator. If the electrical generator is connected to an electrical network by way of a line and/or a transformer then the voltage produced by the electrical generator is desirably so regulated that the value thereof is in the order of magnitude of the value of the network voltage or corresponds thereto. That avoids undesirably high or low voltages at the generator side. Usually the network voltage is substantially constant if it involves a substantially rigid network.

Preferred embodiments of the invention are described in greater detail hereinafter with reference to the accompanying drawings in which:

Figures 1 to 4 show various voltage and current configurations,

Figure 5 shows the harmonic component from the current configuration of Figure 4,

Figure 6 diagrammatically shows a network spur to which a wind power installation and consumer are connected,

Figure 7 shows an equivalent circuit diagram of an electrical line,

Figure 8 shows an equivalent circuit diagram of an electrical network with a transformer and an electrical overhead line (a) to which an electrical generator of a wind power installation is connected, as well as vector diagrams (b to e) representing various operating conditions,

Figure 9 shows a schematic circuit diagram of an arrangement for compensating for harmonic currents in a tap line, and

Figure 10 shows a schematic circuit diagram of an arrangement for compensating for harmonic currents in an electrical network.

The occurrence of fundamental oscillation reactive powers in an electrical network has already long been known. Figures 1 to 3 show various voltage and current configurations.

Figure 1 shows a situation in which there is no reactive power, that is to say voltage U and current I are not phase-shifted. The current neither leads nor trails the voltage. There is therefore no fundamental oscillation reactive power.

Figure 2 shows the situation in which the current I trails the voltage U in respect of time. In this respect, inductive reactive power is required, which is the case with most electrical consumers as they - such as for example electric motors - have inductors.

Figure 3 shows the situation in which the current I leads the voltage U in respect of time. Capacitive reactive power is required in this case.

Figure 6 shows an arrangement in which a wind power installation 2 is connected to a network spur. Consumers 6 are connected from the beginning (point A) to the end (point E) of the network spur or the electrical line 4. If the wind power installation 2 is not feeding into the network, the voltage drops increasingly from the beginning (point A) to the end (point E) of the line 4; the voltage at the point E and the most closely adjacent last consumer 6 is thus lower than at the point A and the first consumer 6 which is most closely adjacent to that point A, on that electrical line 4. If now the wind power installation 2 or a larger wind park is connected at the end of the electrical line 4 at point E in Figure 6 and current is fed into the electrical line 4 the connection voltage at the point E of the electrical line 4 rises in an extreme fashion. The situation which occurs is now the reverse of the case without the wind power installation 2 connected at the end of the electrical line 4.

For the situation where the electrical line is in the form of a free or overhead line (no ground cable), such a line in fact essentially represents

an inductor. In comparison ground cables generally represent a damped capacitor. In that respect attention is directed to the equivalent circuit diagram of a line, as shown in Figure 7.

The voltage at the feed-in point (point E in Figure 6) can be regulated by means of reactive power regulation at the wind power installation. Preferably an inverter is used for that purpose.

Figure 8a shows an equivalent circuit diagram wherein the electrical generator 3 of the wind power installation 2 is connected by way of a line and a transformer to an electrical network (not shown) which is usually a fixed network. Figures 8b to 8e show vector diagrams in relation to various operating conditions. In case A as shown in Figure 8b the generator 3 of the wind power installation 2 only feeds active power into the electrical network 10; it can be seen immediately that the voltage U_{line} at the feed-in point (point E) is higher than the voltage $U_{network}$ at the point A. In case B as shown in Figure 8c a component of inductive reactive power is fed into the network in addition to the active power and it can be seen that the voltages U_{line} and $U_{network}$ at the end at point E and at the beginning point A are equal. The case C shown in Figure 8d illustrates in comparison that too much inductive reactive power is being fed into the network; the consequence of this is that the voltage U_{line} at the point E becomes too low. The case D in Figure 8e shows the situation when excessive capacitive reactive power is being fed into the network; consequently the voltage U_{line} at the feed-in point/point E rises very greatly in relation to the voltage $U_{network}$. The latter situation absolutely has to be avoided.

To provide for reactive power compensation an inverter (not shown) is connected between the generator 3 and the point E as shown in Figure 8a. Now the function of such an inverter is to exactly follow a predetermined voltage value insofar as the cos φ of the output current is correspondingly rapidly and dynamically regulated.

In addition harmonic reactive powers occur in the electrical network. More specifically, electrical consumers increasingly require a current which includes harmonics or produce harmonics in the electrical network, such as for example television units which at the input have a rectifier or industrial

operations which operate regulated rectifier drives. Figure 4 shows a situation in which harmonic reactive power is required. The voltage configuration U is virtually sinusoidal while the current I, besides the fundamental oscillation, also includes harmonics. It is possible to clearly see here the fifth harmonic. Figure 5 shows the required fifth harmonic as a separate component In of the current I.

Such harmonics in the current configuration (current harmonics) cause in the electrical network voltage harmonics which adversely affect the quality of the voltage in the electrical network. It is therefore necessary for such harmonic reactive powers also to be compensated.

Figure 9 shows a tap line 11 which is connected with its one end (at the left in Figure 9) to an electrical network (not shown) while consumers 6 are connected to the other end thereof (at the right in Figure 9). Such a tap line 11 can for example supply an industrial area or park or one or more villages with electric current. The current flowing to the consumers 6 is measured by means of a current transformer 12. The measurement signal from the transformer 12 is passed to an evaluation circuit 14 which continuously analyses on-line which current harmonics are contained in the current on the tap line 11. That measurement results serves as a reference value which is fed as an output signal to an inverter 16 which then produces substantially at the same time the required harmonics and feeds same into the electrical line 11 upstream of the transformer 12. That ensures that the required harmonics reactive power is produced by the inverter 16 for compensation of the harmonic reactive power present in the electrical network, and is not taken from the electrical network.

Figure 10 diagrammatically shows the electrical network 10 whose voltage is measured by means of a voltage transformer 18. The measurement signal from the voltage transformer 18 is fed to an evaluation device 20. There is also a reference value device 22 which predetermines the desired voltage configuration. The output signal of the voltage device 20 is deducted by a subtracting device 24 from the output signal of the reference value device 22 and the difference output signal, resulting therefrom, from the subtracting device 24 is fed to the inverter 10

which then substantially at the same time produces the required harmonics in order to compensate for the harmonic reactive power in the electrical network. In this arrangement therefore the network voltage is measured by means of the voltage transformer 18 and the evaluation device 20 serves to detect which harmonics are contained in the voltage configuration. More specifically the harmonic currents in the electrical network 10 produce at the network impedance voltage drops corresponding to the frequency and amplitude thereof. The values which are measured and calculated in that way are predetermined for the inverter 16 as current reference values. The inverter 16 then produces, in accordance with the reference values, the current harmonics with the required frequencies, amplitudes and phase positions.